Prospectus

Focus Group on the Astrobiological Exploration of Titan

Chair: Jonathan I. Lunine, The University of Arizona
(Part of the University of Washington NAI Consortium)

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Background

The known organic environments in the solar system other than the Earth and certain meteorites are in the outer solar system. Those of astrobiological interest or potential are Europa, Titan, and comets. Europa may contain organic compounds in a subcrustal liquid water environment, but this assumption will not be tested until after 2010. Titan is of interest because it is known to generate suites of hydrocarbons and nitriles in its stratosphere, which then fall to the surface and are protected from damaging particle and UV radiation by a thick atmosphere. Further chemistry, including in the presence of transient and localized areas of liquid water, may proceed on the surface in staccato fashion over geologic time. Europa and Mars have been the subjects of two successful NAI focus groups that have now been running for several years. A focus group for Titan is timely. The Cassini-Huygens mission will initiate the detailed exploration of Titan in less than three years, and NASA is looking now at mission designs for post Cassini-Huygens missions to Titan. An NAI focus group on the astrobiological exploration of Titan beyond Cassini-Huygens will involve the institute in planning such a mission, and will involve the broader astrobiological community in a coherent fashion.

Significance to Astrobiology

Since the discovery of a methane atmosphere around Titan by Gerard Kuiper in 1944, Titan has been a world that has attracted much exobiological interest. In the 1970s, before spacecraft reconnaissance established surface conditions with certainty, much of this interest centered around the possibility that the greenhouse effect of a thick atmosphere could permit hospitable surface conditions. The Voyager 1 encounter in 1980 showed that while the atmosphere was a familiar one in some respects (1.5 bar, mostly molecular nitrogen), the surface temperature of 94K was far too low for liquid water (Coustenis and Taylor 1999).

Many organic compounds have been detected in Titan's atmosphere. These form as a result of the recombination of molecular fragments produced by methane (and nitrogen) photolysis. Ultraviolet solar radiation is primarily responsible, although irradiation by electrons in Saturn's magnetosphere is an additional energy source. The ultimate fate of these compounds is to condense at or near the base of Titan's stratosphere and be deposited as liquids or solids on the surface (Yung *et al.* 1984).

Titan's photochemistry is of keen interest for modelers of atmospheric chemistry. However, by itself it goes but a little ways towards addressing the origins of life, a connection that is sometimes used in the popular press to justify the exploration of Titan. There are two aspects of the photochemistry that limit its immediate relevance to the origin of life question. First, the free radical processes that drive the chemistry of Titan's stratosphere have little specificity and, in the absence of a catalyst, do not result (for example) in chiral compounds composed of a single enantiomer. This situation is perfectly analogous to that in Earth's stratosphere, where free radical chemistry of primarily oxygen and hydrogen in the presence of ultraviolet light creates and destroys interesting species (water, ozone) but is irrelevant to the synthesis of biological or prebiotic polymers. If there is to be any chemistry relevant to pre-biotic synthesis on Titan it must be occurring on or near the surface, acting on the products of stratospheric chemistry and powered by sources other than direct solar ultraviolet radiation.

The second aspect is that, at a level above 10 parts per million, Titan's atmosphere is essentially bereft of oxygen or oxygen-containing compounds like water: even the most abundant (CO) is present only at a few tens of ppm. Although the early Earth similarly lacked molecular oxygen, carbon dioxide was an important or even dominant constituent of its atmosphere. The lack of oxygen-bearing compounds in Titan's atmosphere is a crucial point for two reasons. First is that the chemistry that sustains life on Earth is mediated in liquid water - it requires liquid water as a solvent. Second, virtually every organic molecule of biochemical interest contains some oxygen (that means every amino acid - and therefore every protein and enzyme - every sugar, every fatty acid, and DNA itself). If there is no way to incorporate oxygen into the chemical chain in the atmosphere (and there is not under current conditions or those obtained in all but the first 10% of Titan's history) then the organics that made in Titan's atmosphere will ever be sterile nitriles and hydrocarbons. On the other hand, experiments have shown that tholins and nitriles are readily hydrolyzed by liquid water into amino acids; e.g., Titan tholin yields about 1% amino acids by mass on hydrolysis (Khare *et al.* 1984). Hence, if the accumulating organics on Titan's surface are exposed to liquid water, an entirely new step in chemical synthesis could be introduced.

Sources of liquid water at the surface of Titan, where deposited organic compounds await aqueous alteration, include cryovolcanism (extrusion of liquid water or--more plausibly--water ammonia solutions on the surface) or medium- to large-sized impacts. Such impacts would gauge out craters in the water ice crust of Titan and leave behind approximately 1% by volume melt water (Artemeva, Pierazzo, Lunine, 2001, LPSC). If ammonia is present, complete refreezing of the liquid water would take up to 10^4 years (Lunine *et al.* 1998). We have no experience with the products of aqueous organic chemistry on such long timescales, or large spatial scales, and it is intriguing that the products of such chemistry would lie preserved in the near-surface crust after refreezing.

Titan, in summary, provides us with a planet-sized laboratory for testing the synthesis of organic compounds in a nearly neutral redox environment, over large spatial scales, both with and without liquid water. These natural chemical experiments could be ongoing today, and the products of such experiments in localized regions of elevated temperatures would be well preserved under the ambient 95 K temperatures and high atmospheric densities that shield the surface from destructive radiation.

The Cassini-Huygens mission will make a complete inventory of the surface from a variety of remote sensing and in situ techniques, over the time period late 2004 through late 2008. The Huygens atmospheric probe will descend to the surface in January 2005. Before and after that the Orbiter will undertake some 45 close flybys of Titan. The result of the Cassini-Huygens mission will be a level of understanding of the geology, geodesy, atmospheric physics and surface-atmosphere interactions on Titan rivaling that for Mars after MGS (with the exception of a lack of a detailed global altimetric map of the body). Further, Cassini-Huygens will provide us with information regarding the distribution and nature of organics spread across the Titan surface. Should there be surface compositional variations in the organics, especially correlated with apparent geologic activity or crustal melting, the interest in returning to Titan to sample those interesting places directly, for signs of oxygen-bearing organics like amino or carboxylic acids for example, will be high.

Indeed, NASA has already expressed interest in initial planning for a post-Cassini mission to Titan, and it appears likely that such a mission will be high on the list of astrobiologically interesting programs in the planetary decadal strategy now being prepared. It has become standard operating procedure for the NAI to play a key role in mission planning for astrobiologically interesting target in part or in whole through conduct of focus groups. The Mars and Europa groups have been very effective in this regard. The Titan Focus group will be as well.

Conduct of the Titan Focus Group and Expected Results

The Excel spreadsheet of Appendix A lists the Titan Focus Group activities quarter by quarter, and shows as well other events during the same time frame (including key Cassini Titan encounters). The Titan Focus Group will be open to all interested parties, but each individual who desires to participate will be asked to identify themselves, their institution, and to commit to a certain amount of time and activity. Most of the work of the group will be by e-mail, but two or three meeting of the focus group organized around convenient ancillary meetings (such as the NAI annual meeting) are anticipated. Quarterly reports of the focus group progress will be submitted to the NAI via direct (telecon) presentation backed up by written material. The final product of the focus group will be a series of four white papers organized around the four themes listed in the spreadsheet. These will be appropriate raw material around which the NAI can generate a set of recommendations to NASA for a follow-on mission to Titan, for the experimental techniques and technologies to be used, for the motivating questions to be addressed by the mission, as well as pointers to preliminary Cassini results that would influence the timing and scoping of such a mission.

The four topical areas that shape the four white papers are staggered in time over the three years of the Titan Focus Group (TFG), and are organized in a logical intellectual order. The TFG will first consider the questions that motivate the astrobiological exploration of Titan, and generate a sharply focussed set of scientific questions and objectives that will constrain the kinds of techniques to be applied post-Cassini. Once this is accomplished, the TFG will move into the phase of considering the techniques that should be used in the exploration of Titan beyond Cassini-Huygens, with a focus on the analysis of the organic chemistry of the surface. The effort will be constrained by the results of the JPL project cited above, by the work of the RPI NSCORT on the subject, and other relevant studies. Experimental organic chemists, and not merely "Titanophiles", will need to be involved in the TFG to ensure that this second topic reaches a realistic conclusion, and they will be actively sought. The third topic depends on the successful completion of the second. It concerns the types of missions to be conducted after Cassini-Huygens, as well as the types of analyses of Cassini-Huygens data required to constrain the next mission. Hence science payloads will be considered and winnowed down into a prioritized list, recommendations on number and types of sampling sites will be made, and explicit discussion of how Cassini-Huygens data should be used to decide on the timing and scope of the mission as well as potential landing sites. Finally, as Cassini-Huygens begins its observations of Titan, the TFG will shift its attention to considering the early results from the first 8 flybys of Titan, and the Probe mission. Enough data products will be released in real time or rapidly after each encounter to enable the TFG to make a preliminary assessment of the nature of Titan's surface from the point of view of the astrobiology questions formulated in the first quartile of the TFG's existence. The TFG will also begin the process of assessing post-Cassini mission feasibility and landing site potentials based on the Cassini data returns.

In addition to the Cassini mission itself, the TFG will have access to mission design capabilities at JPL, through Dr. Pat Beauchamp (P. Beauchamp, pers. comm.), and, as a JPL Distinguished Visiting Scientist, Lunine himself. These capabilities would be exercised in the first half of 2004, when the TFG is considering post-Cassini mission scenarios.

Two other activities parallel the TFG activities in a synergistic way. The NRC's Committee on the Origin and Evolution of Life (COEL), co-chaired by Lunine and UW Professor John Baross, will be initiating a study on the possible nature and environments of life forms very different from that on Earth. The study, informally entitled "Weird Life", will consider the requirements for living processes in exotic environments such as (but not limited to) non-polar or slightly polar hydrocarbon liquids such as those likely to be on Titan today. The TFG will be scooping its scientific questions as the COEL study gets under way, and interaction between the two groups is built into the TFG program (see chart). In mid-2004 Lunine and Dr. Chris Welch of Merck and Co. will host the 4th "Biological Chirality" meeting (which began in 1998 in the small town of Serramazzoni, Italy) at Biosphere 2 in Oracle, Arizona. With the focus on extraterrestrial chiral characterization, the TFG will be invited to participate in the meeting remotely or, for those with funds, in person.

Community

There is a small but active community at work on Titan organic chemistry as well as surface processes, centered in the United States and in France, primarily. About 200 scientists are involved in the Cassini mission, perhaps 1/4 of whom will concern themselves with Titan atmosphere and surface processes. However, there is a broader interest among astrobiologically-inclined scientists in the potential of Titan to provide insights into the origin of life. As evidence of this, Dr. Dirk Schulze-Makuch of the University of Texas organized an e-mail discussion group beginning a year ago. The group serves as an e-mail Think Tank for the subject of Titan and life and is now very active.

Relevance of the TFG to NASA space mission and technology development:

As noted above, the schedule for the three-year Titan Focus Group overlaps very well with the first year of the Cassini-Huygens mission, and it will be possible for the group to have access to and discuss some of the early data products regarding Titan. The prime objective of the group is to ensure the conceptualization and initial study of appropriate techniques for advanced organic analysis on Titan, after Cassini-Huygens. Conduct of the focus group now rather than later is important in shaping mission designs that are now being proferred by JPL on behalf of NASA, for post-Cassini Titan surface missions. Unlike Europa, wherein the Orbiter mission was largely defined before the Europa Focus Group came into existence, the NAI has the opportunity here to organize the nation's astrobiologists to influence the nature and design of a post-Cassini Titan mission up front.

Reference List

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